

1. A perceptual model for determining Noise Masking Ratios, NMRs, for audio signals  $x(t)$  in each cochlea filter band, the method comprising determining a representation of the envelope of the part of said  $x(t)$  that is inside a particular cochlea filter band,

5 quantifying a roughness measure for said envelope, mapping said roughness measure to a NMR for the part of the signal that is inside said particular cochlear filter band.

2. The method of claim 1 wherein said determining a representation of the envelope comprises determining  $e(t)$ , the square of said envelope.

3. The method of claim 1 wherein said determining a representation of said envelope comprises determining  $\tilde{X}(f)$ , where  $X(f)$  is the Fourier transform of  $x(t)$ , and  
5  $\tilde{X}(f)$  is the Fourier transform of the analytic signal corresponding to  $x(t)$ ,  $\tilde{X}(f)$  being a single sided frequency spectrum defined as

$$\tilde{X}(f) = \begin{cases} 0 & f < 0 \\ X(f) & f = 0 \\ 2X(f) & f > 0 \end{cases}$$

for  $f$  extending over a frequency range associated with a human cochlea.

4. The method of claim 3 further comprising filtering said  $\tilde{X}(f)$  by a cochlear filter,  $H_i(f)$ , for  $i = 1, 2, \dots N$  to form representations of said single-sided frequency spectrum for  $N$  discrete bands of said frequency range, said representations given by

5 
$$\tilde{X}_i(f) = \tilde{X}(f) H_i(f).$$

5. The method of claim 4 wherein said determining said envelope further comprises determining  $e_i(t)$  for said  $N$  discrete bands in accordance with

$$e_i(t) = F^{-1} \left\{ \int \tilde{X}_i(\varepsilon) \cdot \tilde{X}_i^*(\varepsilon - f) d\varepsilon \right\}$$

where  $e_i(t)$  is the square of said signal envelope corresponding to the  $i$ th cochlea filter  
5 band having a characteristic frequency  $f_i$ .

6. The method of claim 5 wherein said quantifying a roughness measure for said envelope comprises performing a linear prediction of said envelope,  $e_i(t)$  for each  $i$  to determine corresponding banded roughness measures  $r_s(i)$ .

7. The method of claim 6 wherein said mapping said roughness measure to a NMR comprises normalizing said  $r_s(i)$ , for each  $i$ , with respect to a roughness measure for a pure tone,  $r_t(i)$ , for each  $i$ , to form a normalized roughness measure for each  $i$ .

8. The method of claim 7 wherein said mapping said roughness measure to a NMR further comprises squaring said normalized roughness measure for each  $i$  to form a squared roughness measure for each  $i$ .

9. The method of claim 8 wherein each said squared roughness measure is raised to the 4<sup>th</sup> power to reflect cochlea compression.

10. The method of claim 6 wherein said mapping said roughness measure for each cochlear band  $i$  to a NMR comprises determining

$$NMR_i = c \cdot \left[ \frac{r_s(i)}{r_t(i)} \right]^8,$$

where  $r_t(i)$  is the roughness measure for a pure tone for each  $i$ , and  $c$  is a constant.

11. The method of claim 10 wherein said constant,  $c$ , is determined by performing a linear prediction of the envelope,  $e_i(t)$  for each  $i$  for a white noise input signal, thereby determining corresponding banded roughness measures  $r_n(i)$

substituting said  $r_n(i)$  values for  $r_s(i)$  in

$$NMR_i = c \cdot \left[ \frac{r_s(i)}{r_t(i)} \right]^8,$$

substituting known theoretical values for  $NMR_i$  for white noise in the immediately preceding equation, thereby determining a value,  $c_i$ , for each  $i$ , and

averaging said values of  $c_i$  for all  $i$  to determine said value for  $c$ .

12. A method for coding audio signals  $x(t)$  in the frequency domain, the method comprising

for each band of a cochlear filter having a plurality of bands

determining a representation of the envelope of the part of said  $x(t)$  that is inside a

particular cochlea filter band,

quantifying a roughness measure for said envelope,  
 mapping said roughness measure to a Noise Masking Ratio, NMR, for the part of  
 $x(t)$  that is inside said particular cochlear filter band,  
 quantizing said audio signals in the frequency domain using said NMRs to  
 10 determine quantizing levels.

13. The method of claim 12 wherein said determining a representation of the  
 envelope comprises determining  $e(t)$ , the square of said envelope.

14. The method of claim 12 wherein said determining a representation of said  
 envelope comprises determining  $\tilde{X}(f)$ , where  $X(f)$  is the Fourier transform of  $x(t)$ , and  
 $\tilde{X}(f)$  is the Fourier transform of the analytic signal corresponding to  $x(t)$ ,  $\tilde{X}(f)$  being  
 a single sided frequency spectrum defined as

$$\tilde{X}(f) = \begin{cases} 0 & f < 0 \\ X(f) & f = 0 \\ 2X(f) & f > 0 \end{cases}$$

for  $f$  extending over a frequency range associated with a human cochlea.

15. The method of claim 14 further comprising

filtering said  $\tilde{X}(f)$  by a cochlear filter,  $H_i(f)$ , for  $i = 1, 2, \dots, N$  to form  
 representations of said single-sided frequency spectrum for  $N$  discrete bands of said  
 frequency range, said representations given by

$$\tilde{X}_i(f) = \tilde{X}(f) H_i(f).$$

16. The method of claim 15 wherein said determining said envelope  
 comprises determining  $e_i(t)$  for said  $N$  discrete bands in accordance with

$$e_i(t) = F^{-1} \left\{ \int \tilde{X}_i(\varepsilon) \cdot \tilde{X}_i^*(\varepsilon - f) d\varepsilon \right\}$$

where  $e_i(t)$  is the square of said signal envelope corresponding to the  $i$ th cochlea filter  
 5 band having a characteristic frequency  $f_i$ .

17. The method of claim 17 wherein said quantifying a roughness measure for  
 said envelope comprises performing a linear prediction of said envelope,  $e_i(t)$  for each  $i$  to  
 determine corresponding banded roughness measures  $r_s(i)$ .

18. The method of claim 17 wherein mapping said roughness measure to a NMR comprises normalizing said  $r_s(i)$ , for each  $i$ , with respect to a roughness measure for a pure tone,  $r_t(i)$ , for each  $i$ , to form a normalized roughness measure for each  $i$ .

19. The method of claim 18 wherein said mapping said roughness measure to a NMR further comprises squaring said normalized roughness measure for each  $i$  to form a squared roughness measure for each  $i$ .

20. The method of claim 19 wherein each said squared roughness measure is raised to the 4<sup>th</sup> power to reflect cochlea compression.

21. The method of claim 19 wherein said mapping said roughness measure for each cochlear band  $i$  to a NMR comprises determining

$$NMR_i = c \cdot \left[ \frac{r_s(i)}{r_t(i)} \right]^8,$$

where  $r_t(i)$  is the roughness measure for a pure tone for each  $i$ , and  $c$  is a constant.

22. The method of claim 21 wherein said constant,  $c$ , is determined by performing a linear prediction of the envelope,  $e_i(t)$  for each  $i$  for a white noise input signal, thereby determining corresponding banded roughness measures  $r_n(i)$

substituting said  $r_n(i)$  values for  $r_s(i)$  in

$$NMR_i = c \cdot \left[ \frac{r_s(i)}{r_t(i)} \right]^8,$$

substituting known theoretical values for  $NMR_i$  for white noise in the immediately preceding equation, thereby determining a value,  $c_i$ , for each  $i$ , and

averaging said values of  $c_i$  for all  $i$  to determine said value for  $c$ .